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Upper troposphere circulation anomalies over Asia-Pacific region associated with the interannual variation of Indian summer monsoon

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सार — अच्छे मानसून वर्षों और खराब मानसून वर्षों (एन्सो दक्षिणी दोलन से संबद्ध और इससे असंबद्ध दोनों) के संबंध में अध्ययन के लिए मई के महीने में और मानसून ऋतु (जून-सितम्बर) में पाई जाने वाली परिसंचरण विसंगत के संयुक्त प्रतिरूपों का पता लगाने के लिए 1963 से 1988 तक की अवधि में एशिया प्रशांत महासागर क्षेत्रों के 67 रेडियो सौदे केन्द्रों की मासिक माध्य वेक्टर पवनों और 200 हैक्टापास्कल पर भू विभव ऊँचाइयों का उपयोग किया गया है। अच्छे और खराब मानसून वर्षों के असंगत परिसंचरण लक्षणों में उल्लेखनीय भिन्नताएं पाई गई हैं। अच्छे (खराब) मानसून वर्षों के दौरान मई माह में मध्य एशिया के ऊपर असंगत प्रतिचक्रवातीय (चक्रवातीय) परिसंचरण और प्रशांत महासागर के ऊपर असंगत चक्रवातीय (प्रतिचक्रवातीय) परिसंचरण देखा गया। ये विसंगतियाँ बाद की मानसून ॠतुओं में भी विद्यमान रहीं। इन असंगत परिसंचरण प्रतिरूपों के विकास के प्रमुख प्रक्रमों और उनके परिणामों की इसमें चर्चा की गई है।

ABSTRACT. Monthly mean vector wind and geopotential heights at 200 hPa of 67 radiosonde stations from Asia Pacific regions for the period 1963-1988 are used to examine the composite circulation anomaly patterns for the month of May and the monsoon season (June- September) with respect to good monsoon years and bad monsoon years (both associated with ENSO and not associated with ENSO). There are significant differences in the anomalous circulation features between good and bad monsoon years. During the month of May an anomalous anticyclonic (cyclonic) circulation over-central Asia and an anomalous cyclonic (anticyclonic) circulation over Pacific ocean were observed during good (bad) monsoon years. These anomalies persist in the subsequent monsoon season. The key mechanisms of the development of these anomalous circulation patterns and their consequences are discussed.

Key words - Monsoon, Interannual variability, Snow cover, ENSO, OLR.

1. Introduction

Since long back it has been recognized that monsoon systems, such as the Asian monsoon, of which India is a part, play an important role as a major source of energy in the global scale circulation in the tropics. Yasunari and Seki (1992) explained the role of Asian summer monsoon as a transmitter of climatic signals between the tropics and the extratropics in the seasonal cycle. Consequently, year-to-year variation could be observed in the activity of monsoon. Over the Indian region there is a large interannual variation between so called good monsoon years with above normal rainfall over the region as a whole and bad monsoon years or droughts with deficient rainfall. In a country like India with agro-based economy, agricultural activities depend on the performance of southwest monsoon. The earlier studies on the interannual variability of Indian southwest monsoon are mainly of two types. In the first type of studies (Thapliyal and Kulshrestha 1992, Krishnakumar *et al.* 1995, Hastenrath 1995, Singh and Pai 1996) the rainfall and the global and regional parameters having physical and statistical relationship with the rainfall were quantified and their relationships were utilized to forecast the rainfall quantitatively using techniques like regression, principal, component analysis (PCA) etc.

In the second type of studies (Keshavamurty *et al.* 1980, Verma 1982, Rajeevan 1991, 1993a, Krishnamurti *et al.* 1989, 1990, De *et al.* 1995) mean and anomalous circulation patterns are diagnosed using wind vector, outgoing long-wave radiation (OLR) and cloud fields for significant signals prior to the monsoon season and their persistence during the subsequent monsoon season. In order to have better confidence in the quantitative forecast, qualitative behaviour of circulation features prior to the monsoon season should be watched thoroughly. Using composite height and thermal circulation anomalies some researchers (Keshavamurty *et al.* 1980, Verma 1982, Rajeevan 1991) suggested that upper tropospheric cyclonic (anticyclonic) anomalies persist over northwest India during May and June months of drought (flood) years. Rajeevan (1993a) later observed that these are part of large scale circulation anom-

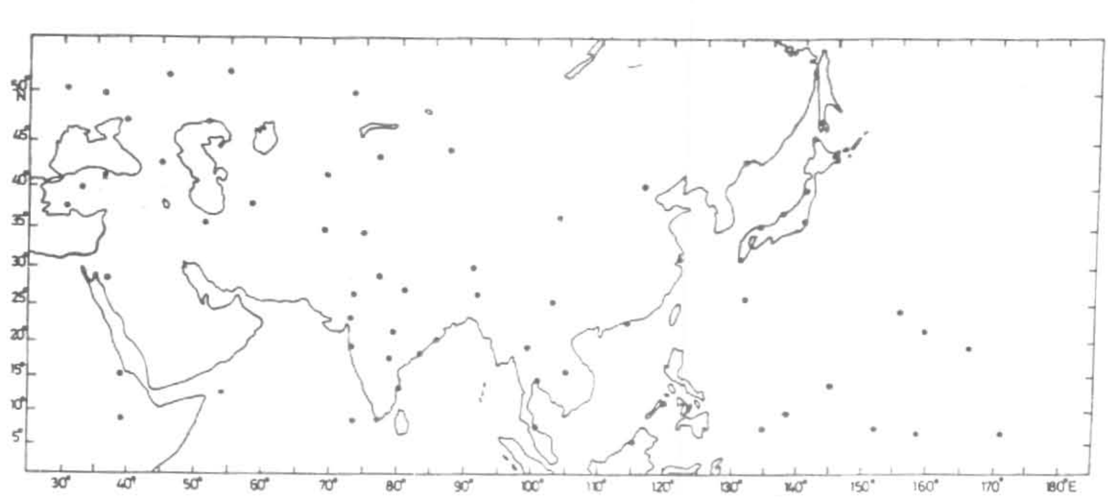


Fig.1. The radiosonde stations over Asia-Pacific regions used for this study

aly observed over the central Asia. However, in the above studies anomaly patterns were examined over limited region only with smaller data sets. Since the interannual variabilility of monsoon is significantly influenced by planetary scale atmospheric fluctuations, it is necessary to examine the behaviour of three dimensional flow at planetary scale rather than limited over smaller regions.

In this paper, we examine the upper tropospheric planetary scale circulation anomalies over Asia-Pacific region associated with the variability of summer monsoon using the 200 hPa wind vector and geopotential height of a large period. Unlike the earlier studies, in this study, circulation anomalies are examined separately for bad monsoon years with and without the influence of ENSO. This was done to understand the physical forcings other than ENSO.

2. Data and method of study

Monthly mean vector winds and geopotential heights at 200 hPa of 67 radiosonde stations over Asia-Pacific regions for the period 1963-88 are used for this study. The stations considered are shown in Fig.1. These data are obtained from National Center for Atmospheric Research (NCAR), USA. These data are basically published in 'Monthly Climatic Records of the World' by NOAA, USA. These data are compiled, quality controlled and digitized by NCAR To support the shift in circulation patterns during ENSO years, monthly outgoing longwave radiation (OLR) data obtained from Climate Analysis Center (CAC) of NOAA, USA are also used. These data are derived from NOAA polar orbiting satellites, digitized on a global grid of 2.5° x 2.5°. These data are later smoothed to 5° x 5° scale. We have used the data for the period 1979-88. In this study we examine composite OLR anomalies with respect to ENSO years (1982 and 1987) from a base period of 10 years (1979-88).

Area weighted all India monsoon rainfall data are taken from India Meteorological Department (IMD) records (Thapliyal and Kulshrestha 1992). Fig.2 shows the time series of percentage departure of the area weighted all India monsoon season rainfall from 1875 to 1996. The years in which the percentage departure was >10% are termed as good monsoon years. Similarly the years in which the percentage departure is <-10% are called bad monsoon years. There are numerous literature on the influence of El Nino Southern Oscillation (ENSO) phenomena on Indian summer monsoon (Parthasarathy and Pant 1985, Shukla and Paolino 1983). The ENSO years during the period 1875-1995 are shown as hatched bars. It is interesting to note that, there are some bad monsoon years during non-ENSO years also. De and Vaidya (1996) have also pointed out this in a recent study. Therefore, it is evident that there are other major physical forcings which play important role in modulating Indian summer monsoon rainfall.

With all the available monthly vector wind and geopotential height data monthly means of vector winds and geopotential heights are calculated. From these 'mean' data monthly anomalies for each month are then calculated. These monthly anomalies are further averaged and made composite anomaly maps in respect of following three cases: (*i*) Good monsoon years (1970, 1975, 1983 and 1988), (*ii*) Bad monsoon years during ENSO years (1965, 1972, 1982 and 1987) and (*iii*) Bad monsoon years during the Non-ENSO years (1966, 1968, 1974, 1979 and 1986). These composite circulation anomalies in respect of the above cases are discussed for the month of May and the monsoon season (June to September) separately.

3. Results

3.1. *Good monsoon years (1970, 1975, 1983 and 1988)*

Figs. 3 (a&b) show the composite circulation anomalies at 200 hPa for the month of May and the monsoon season

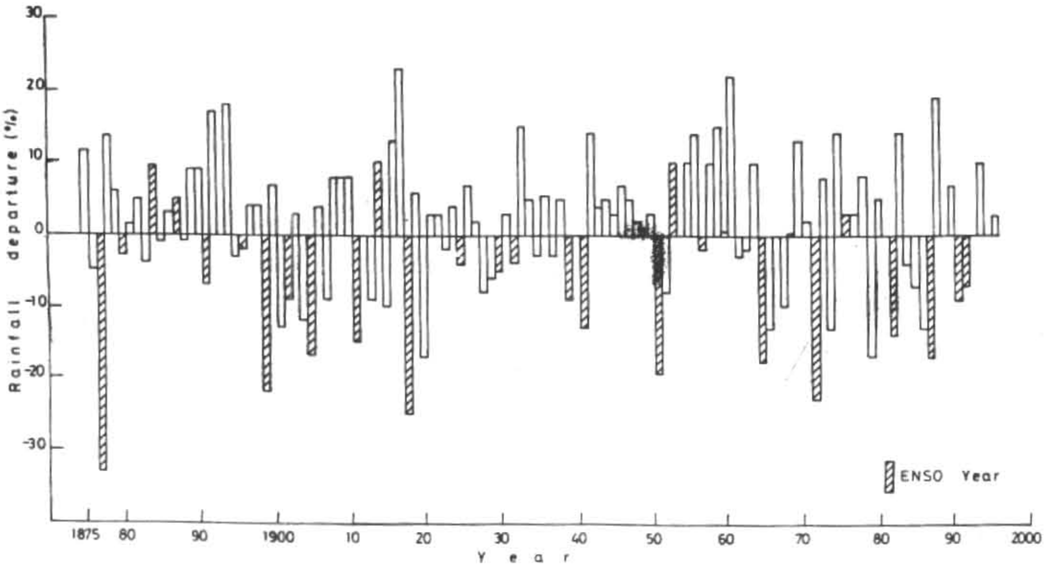


Fig.2. Area-weighted all India monsoon rainfall time series for the period 1875-1996. The ENSO years are shown as hatched bars

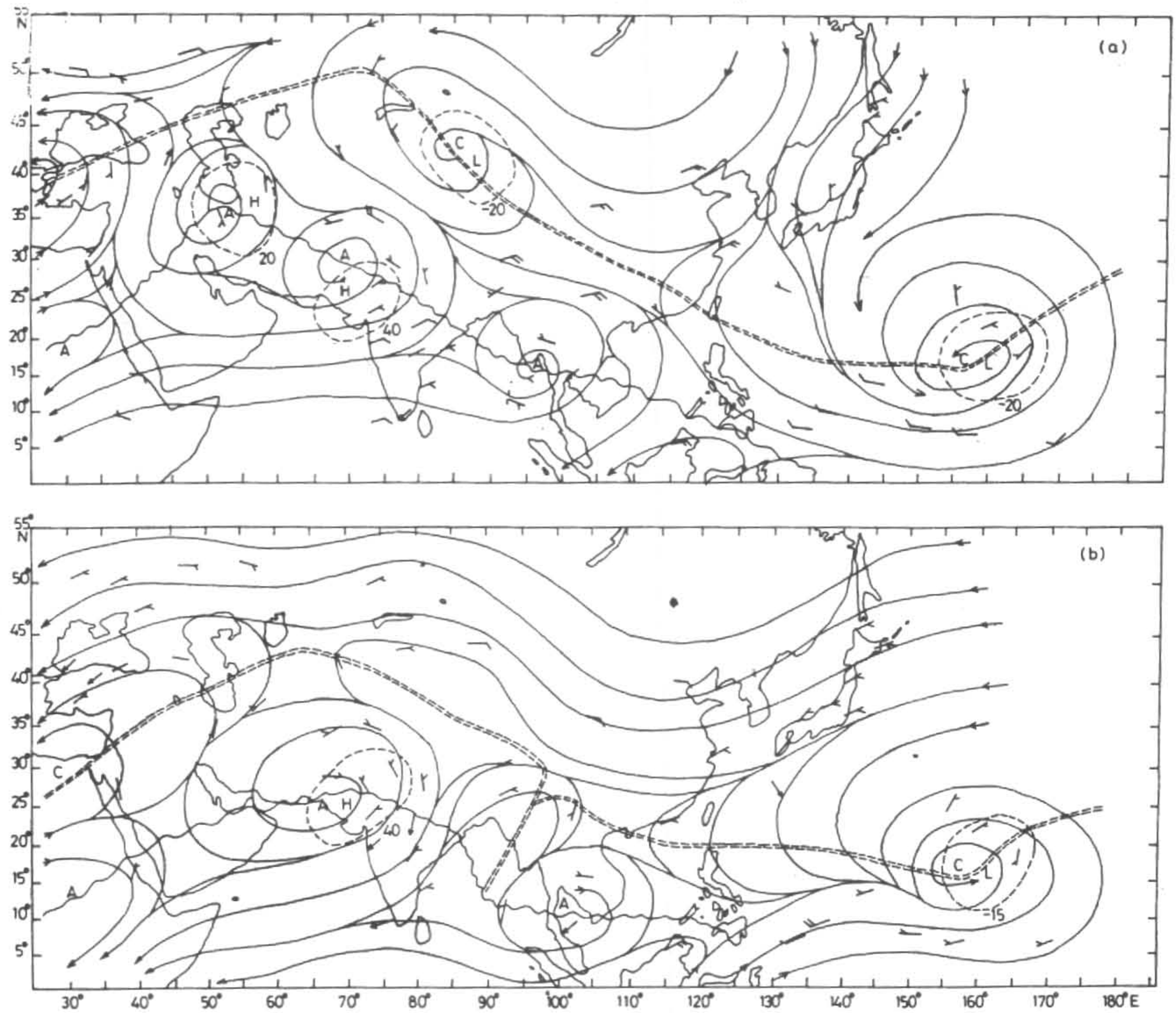
respectively for the good monsoon case (case I). During the month of May an anomalous anticyclonic circulation with warm core is observed over northwest India alongwith another anticyclonic circulation centered over south Caspian Sea and neighbouring central Asia. The ridge line is observed to pass all along from central Asia to northwest pacific through central India. Another important feature is, relatively strong anomalous cyclonic circulation with a cold core over northwest Pacific near Wake island. The associated anomalous trough is observed extending westward through northern parts of Caspian Sea across central Asia north of Aral Sea to another anomalous circulation over Mediterranean Sea and neighbouring land area. According to Krishnamurti *et al.* (1990) during 1988, which was a good monsoon year for India the 200 hPa velocity potential field exhibited a planetary scale geometry with divergent outflows emanating from the monsoon regions with its descending branches to the east found over the eastern Pacific and north America.

During the monsoon season the anticyclonic circulations with warm core over the northwest India and central Asia combine to occupy larger aerial extent. Easterly anomalies are observed throughout the Indian region which is observed during the month of May also. The anomalous cyclonic circulation with cold core over northwest pacific persisted with a larger aerial extension reaching upto south China Sea. The anticyclonic circulation over Indo-China region is observed over southeast Asia. The anomalous cyclonic circulation over Mediterranean Sea and neighbourhood also persists but with a slight southward shift. The anomalous trough from this system, which during the month of May is passing across the central Asia north of Aral Sea, also showed southward shift. As a whole the mean features of circulation anomaly pattern observed during the month of May persisted and strengthened during the subsequent monsoon season.

3.2. *Bad monsoon during ENSO years (1965, 1972, 1982 and 1987)*

Figs. 4(a&b) show the composite circulation at 200 hPa for the month of May and the monsoon season respectively in the case of bad monsoon during the ENSO years (case II). During the month of May, the prominent anomalous circulation features are the large scale anomalous cyclonic circulation with a cold core over Iran and neighbourhood southeast of Caspian Sea and a large scale anomalous anticyclone with warm core over equatorial central pacific centered around date line. The ridge from this anticyclone is extending westward up to Andaman Sea through south China Sea. An anomalous anticyclonic circulation with warm core also is observed around Aral Sea. The ridge from this system extended westward through north Caspian Sea to another anomalous anticyclonic circulation over Black Sea. Other anomalous anticyclonic circulations are observed over northeast India and adjoining Myanmar region and over Red Sea and neighbouring land areas. The anomalous trough line from the cyclonic circulation anomaly over Iran and neighbourhood extends upto another anomalous cyclonic circulation over the eastern parts of south China.

During the monsoon season the anomalous cyclonic circulation over Iran and neighbourhood strengthened and extended to a large area and centered over the central Asia southeast of Caspian Sea. Associated trough is extending upto east Asia. As a result, large scale westerly anomalies are observed over the Asian monsoon region. The anomalous anticyclonic circulation over central Pacific observed during the month of May also persist during the subsequent monsoon season. However, the anomalous anticyclonic cir-



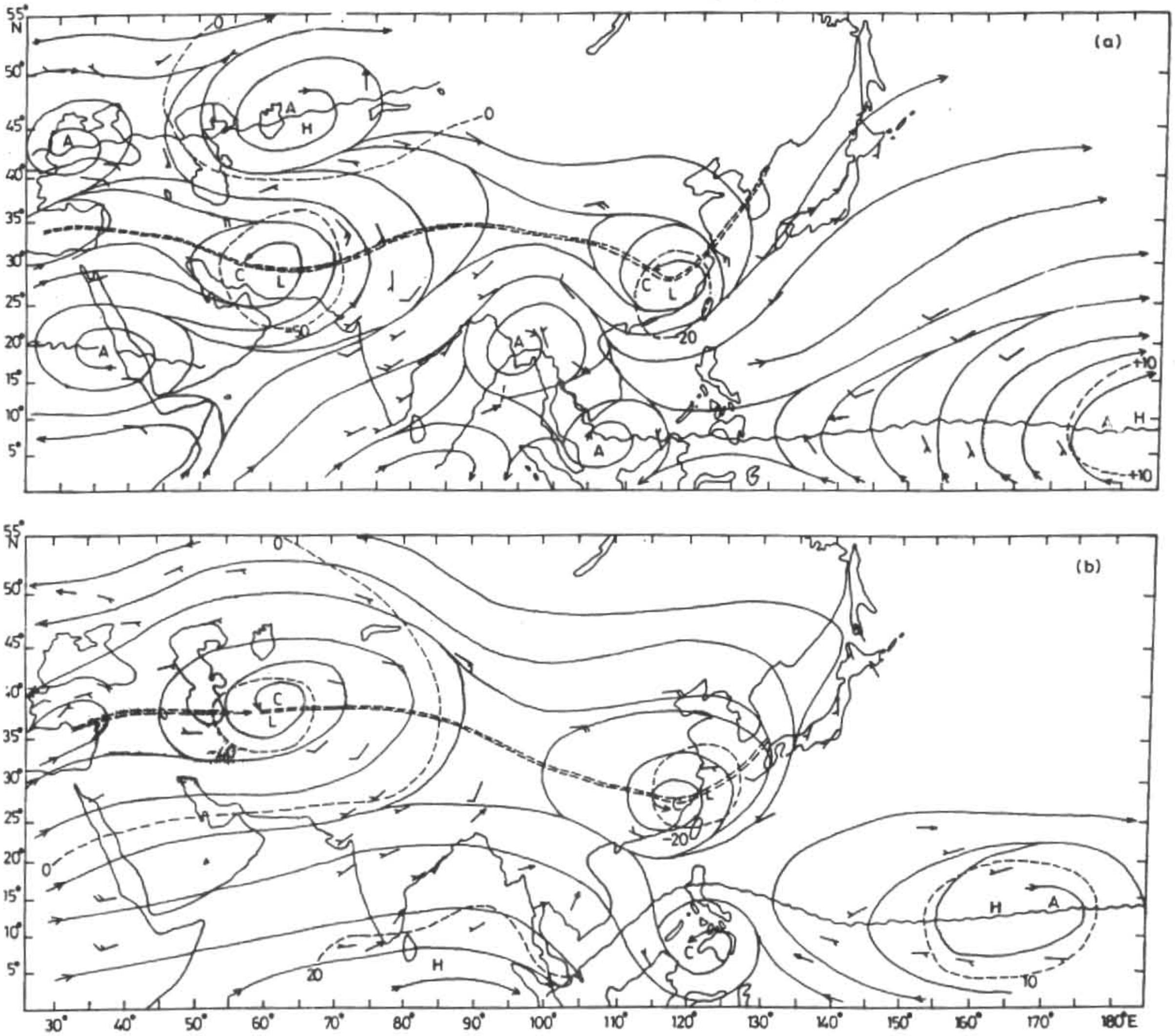
Figs.3 (a&b). Composite wind and geopotential height anomalies at 200 hPa for (a) the month of May and (b) monsoon season (June to September) for good monsoon years (case I). Anomalies of geopotential heights are indicated by dotted lines. A and C represent anticyclone and cyclone respectively. H and L represent contour high and low respectively

culation near Aral Sea and its associated ridge line passing across the central Asia is not observed.

3.3. *Bad monsoon during non-ENSO years (1966, 1968, 1974, 1979 and 1986)*

Figs.5(a & b) show the composite circulation anomalies at 200 hPa for the month of May and monsoon season respectively in the case of bad monsoon years when ENSO phenomenon was not present (case III).

The features of circulation anomalies in this case are almost similar to case II, *i.e.* bad monsoon years during ENSO years. For example, the anomalous cyclonic circulation over central Asia and anomalous anticyclonic circulation over Pacific Ocean are observed in this case also. During the month of May the anomalous cyclonic circulation with cold core over central Asia is situated near around Aral Sea. The anomalous trough from this system extends eastward of another anomalous cyclonic circulation centered over eastern coast of north China and neighbourhood and westward of Mediterranean Sea and neighbourhood. The anomalous anticyclonic circulation over the Pacific Ocean was centered over northeast Pacific near Wake island. The anomalous ridge line from this system extends westward through an anomalous anticyclone over south-central China to another anomalous anticyclone over Red Sea and neighbourhood. These anomalous circulation features over central Asia and northwest Pacific observed during the month of May persist during the subsequent monsoon season. Large scale westerly intrusion over northwest India is observed in this case also.

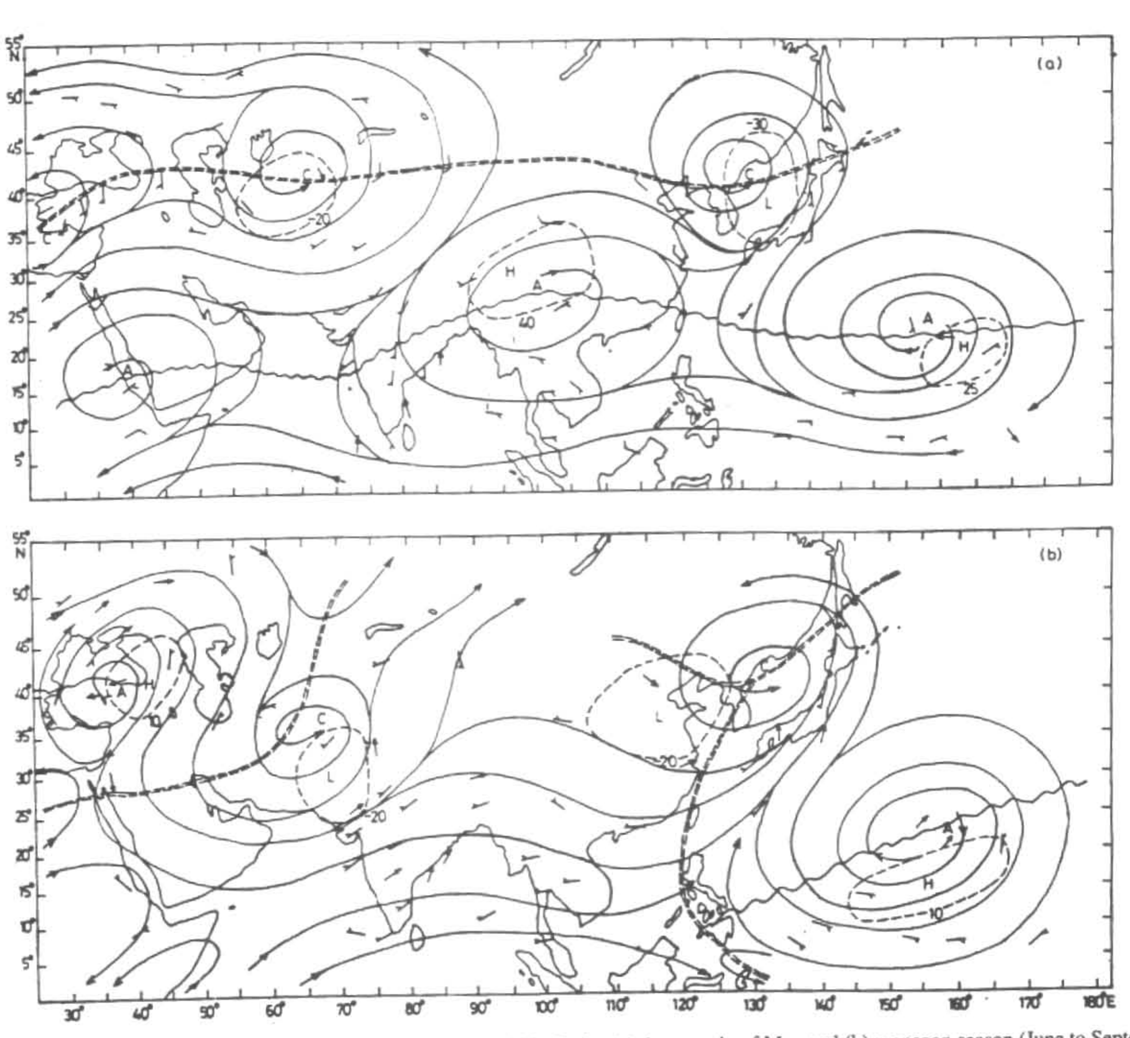


Figs. 4(a&b). Composite wind and geopotential height anomalies at 200 hPa for (a) the month of May and (b) monsoon season (June to September) for bad monsoon during ENSO years (case II). Anomalies of geopotential heights are indicated by dotted lines

4. Discussion

In the earlier section, we have noticed that there are significant differences in the patterns of anomalous circulation features between good monsoon years and bad monsoon years. The most prominent feature which came out from this analysis is the dipole-like anomaly pattern between anomalous circulations over the central Asia and Pacific and the reversal of the polarity of this dipole pattern between good and bad monsoon years. The anomalous anticyclonic circulation over central Asia and anomalous cyclonic circulation over Pacific Ocean during good monsoon years are reversed during bad monsoon years. In association with this reversal the east-west trough/ridge pattern also is reversed accordingly. For example, during good monsoon years there is an east-west anomalous trough passing across the central Asia. During ENSO bad monsoon years in the month of May this east-west anomalous trough near the Aral Sea is replaced by an east-west anomalous ridge. In the monsoon season, however, this anomalous ridge is absent on the chart probably due to the northward extension and shifting of the more stronger anomalous cyclonic circulation over the central Asia. The anomaly wind pattern of non-ENSO years though resemble to that of ENSO bad years, the whole pattern shows a major northward shift particularly during the month of May [Figs. 4 (a) & 5(a)]. For example, in the month of May during the ENSO bad monsoon years, the anomalous cyclonic circulation with cold core over central Asia is situated over Iran and neighbourhood and during the non-ENSO bad monsoon years, it is situated much north near to Aral Sea. The trough line associated with this system also shows a similar northward shift. As a result, the anomalous ridge line across the central Asia appeared during the month of May of ENSO bad monsoon years is not observed during both the month of May and monsoon season of non-ENSO bad monsoon years.

The anomalous cyclonic circulation over central Asia is an important anomaly pattern during bad monsoon years,



Figs. 5(a&b). Composite wind and geopotential height anomalies at 200 hPa for (a) the month of May and (b) monsoon season (June to September) for bad monsoon during non-ENSO years (Case III). Anomalies of geopotential heights are indicated by dotted lines

as discussed by Keshavamurty *et al.* (1980), Verma (1982), Rajeevan (1993a) and Krishnamurti *et al.* (1989). This study, which used more number of years of data confirms this pattern. The anomalous cyclonic circulation over central Asia and associated westerly wind anomalies over Indian region also revealed the composite circulation pattern of ENSO events (Arkin 1982, Yasunari 1987). This pattern which is observed during the month of May itself is not conducive to convective activity over Indian region, due to large scale intrusion of dry and cold westerlies into the Indian region and also by reducing the upper tropospheric equatorward pressure gradient.

During good monsoon years, anomalous anticyclonic circulation is observed over northwest India and neighbouring central Asia, and easterly wind anomalies are observed over Indian region. Similarly, the anomaly pattern over Pacific region also is reversed between good and bad monsoon years. During good monsoon years there is an anomalous cyclonic circulation over northwest Pacific. This can be associated with the depressed convective activity over that region. In bad monsoon years associated with ENSO, the anomalous anticyclonic circulation is observed over the central equatorial Pacific region close to the dateline. This is quite clear, that during ENSO years the convective activities shift to south-eastwards close to the date line, in association with large positive sea surface temperature (SST) anomalies, typically observed near the dateline during ENSO years. The excessive convective activity observed near dateline is supported by large negative outgoing long-wave radiation (OLR) anomalies which persist over equatorial central Pacific (Fig.6). Keshavamurty (1982) and Bhalme *et al.* (1990) also observed an eastward shift in the planetary waves during the bad monsoon years induced by excessive warm SST anomalies associated with ENSO.

During bad monsoon years without ENSO, this anomalous anticyclonic circulation persists over subtropical Pacific regions. This suggests, excessive convective activity around that region. The typhoon activity over northwest

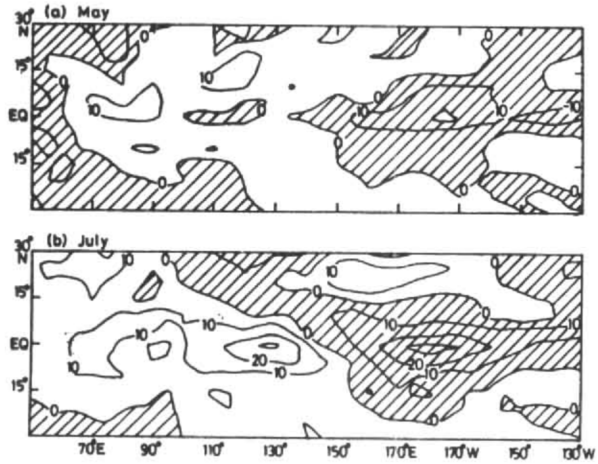


Fig.6. Outgoing longwave radiation (OLR) anomalies (Wm^{-2}) for the month of May and July during ENSO years. Negative anomalies are indicated by stippled areas

Pacific region peaks during monsoon season. Earlier studies suggest that during the bad monsoon years, typhoon activity as measured by typhoon days is above normal (Rajeevan 1993b). The .anomalous anticyclonic circulation over subtropical Pacific region may be associated with the excess typhoon activity over northwest Pacific. During 1966, 1968, 1974, and 1986 (the year 1979 is excluded because the typhoon days during that year are 10 days below normal) the average typhoon days is more than normal by about 6 days with a standard deviation (SD) of about 4 days. During the ENSO years, typhoon activity is found to be more than non-ENSO years due to the eastward spreading of above normal SST over Pacific. During the four ENSO years (1965, 1972, 1982 and 1987) the average typhoon days is more than normal by about 16 days (SD = 4 days). That for the good monsoon years (1970, 1975, 1983 and 1988) is below normal by 11 days (SD = 8 days).

The development of anomalous cyclonic circulation pattern during May and subsequent monsoon season over central Asia during both ENSO and non-ENSO years may be related with snow cover anomaly over Eurasia. Yasunari and Seki (1992) discussed the physical mechanisms leading to the anomalous snow cover area over Eurasia. The anomalous state of Asian monsoon and ocean-atmosphere system in the tropical Pacific produces the anomalous atmospheric circulation over the subtropics and the extratropics through early winter. In the mid-winter, this anomalous circulation over the north Pacific evolved to the hemispheric winter anomalous circulation with wave number one and/or two structure. The anomalous circulation over Eurasia associated with this hemispheric anomalous flow regime seems to provide a favourable conditions for the extensive (or diminished) snow cover area over Asia. There is a general inverse relationship between Eurasian snow cover (ESC) and Indian monsoon (Yang 1996, Shankar Rao *et al.* 1996). During the winter of bad monsoon years (both ENSO and non-ENSO years) used in this study the ESC was in general above normal. The larger albedo due to above normal snow cover reduces the land heating during the subsequent months and the water vapour is evaporated into the atmosphere due to the melting of snow. Both these processes cool and stabilize the lower atmosphere (Shukla 1987).

Following winters of more snow cover, Shankar Rao *et al.* (1996) observed anomalously colder lower troposphere and lower anomalous pressure in the upper troposphere over Asia and the corresponding summer monsoon was found weaker. The anomalous upper tropospheric cyclonic circulation with cold core over central Asia and associated anomalous westerly winds over Indian region observed in this study during bad monsoon years (ENSO and non-ENSO years) may be associated with this anomalous low pressure in the upper troposphere, which indicates the weakened upper tropospheric high. This weaker upper tropospheric high reduces the equatorward upper tropospheric pressure gradient and weakens the monsoon circulation system. There are numerous sensitive studies on the effect of ESC on the Indian summer monsoon (Barnett *et al.* 1989, Yasunari *et al.* 1991). The snow cover response to monsoon circulation was recently addressed by Vernerker *et al.* (1995) using the COLA GCM. It was found that excess snow cover during winter/spring cause reduced mid- tropospheric meridional temperature gradient over the Indian peninsula which weakens the monsoon circulation. From the above discussions, it is very clear that the anomaly pattern over central Asia can be used as a precursor of bad monsoon years, irrespective of ENSO years. It is also interesting to note that there exist some predictive signals in the anomaly pattern during the month of May, for the ensuing monsoon season.

5. Conclusions

From this study, the following conclusions can be drawn:

(*i*) There are significant differences in the 200 hPa circulation and height anomaly pattern over Asia-Pacific region between good and bad monsoon years over India. It is found that cold cyclonic (warm anticyclonic) circulation anomaly persists over central Asia during bad (good) monsoon years, confirming the earlier results. Similarly cold cyclonic (warm anticyclonic) circulation anomaly persists over west Pacific region during good (bad) monsoon years. Associated with the anomaly pattern of bad monsoon years over central Asia large scale intrusion of dry and cold westerlies of upper troposphere is also observed over the Indian region. Joseph (1978) observed this feature to be persisting on many occasions, right from the preceding winter.

(*ii*) The anomaly patterns of the bad monsoon case during ENSO and non-ENSO years are almost similar except for an appreciable northward shift of prominent anomalous circulations.

(*iii*) The anticyclonic circulation anomalies over equatorial central Pacific during bad monsoon years (ENSO years) may be due to the eastward shifting of the convective activities associated with the ascending branch of the Walker circulation and that over subtropical northwest Pacific during bad monsoon years (non-ENSO years) may be associated with the above normal typhoon activity in that region. The observed shift during the ENSO bad monsoon years in the anomaly pattern over the Pacific Ocean receives some supporting evidence from the earlier studies (Keshavamurty 1982, Bhalme *et al.* 1990) where an eastward shift was observed in the planetary waves induced by excessive warm SST anomalies associated with ENSO.

(*iv*) The cold cyclonic circulation anomalies over central Ašia during bad monsoon case may be caused due to excessive snow cover resulting in reduced surface heating and associated cooling of lower and mid-troposphere due to the evaporation of water vapour from the melting snow. The signal in the anomaly pattern observed during the month of May, which persisted during subsequent monsoon season, may be useful for assessing the performance of ensuing monsoon qualitatively.

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References

Arkin, P.A., 1982, "The relationship between interannual variability in the 200 mb tropical wind field and the southern oscillation", *Mon. Wea. Rev.*, **110**, 1393-1404.

Barnett, T.P., Dumenil, L., Schelse, V., Roekner, E. and Latif, M., 1989, "The effect of Eurasian snow cover on regional and global variations", *J. Atmos. Sci.*, **46**, 661-685.

Bhalme, H.N., Sikder, A.B. and Jadhav, S.K., 1990, "Coupling between the El-Nino and Planetary-scale waves and their linkage with the Indian monsoon rainfall", *J. Meteorol. Atmos Phys.*, **44**, 293-305.

De, U.S., Prasad, O. and Vaidya, D.V., 1995, "The influence of southern hemispheric equatorial trough on rainfall during southwest monsoon", *Theor. Appl. Climatol.*, **52**, 177-181.

De, U.S. and Vaidya, D.V., 1996, "Recent decadal variability of monsoon, *Vayu Mandal*, **26**, 50-55.

Hasternrath, S., 1995, "Recent advances in tropical climate prediction, *J. Climate*, **8**, 1519 - 1532.

Joseph, P.V., 1978, "Subtropical westerlies in relation to large scale failure of Indian monsoon", *Indian J. Meteor. Hydrol. Geophys.*, **29**, 412-418.

Keshavamurty, R.N., Satyan, V., Dash, S.K. and Sinha, H.S.S., 1980, "Shift of quasi-stationary feature during active and break monsoon", *Proc. Ind. Acad. Sci.*), (*Earth and Planet Sci*), **89**, 209- 214.

Keshavamurty, R.N., 1982, "Response of the atmosphere to sea surface temperature anomalies over the equatorial Pacific and the teleconnections of the southern oscillation", *J. Atmos Sci.*, **39**, 1241-1259.

Krishna Kumar, K., Soman, M.K. and Rupa Kumar, K., 1995, "Seasonal forecasting of Indian summer monsoon rainfall", *Weather*, **50**, 449-467.

Krishnamurti, T.N., Bedi, H.S. and Subramaniam, M., 1989, "The summer monsoon of 1997", *J. Climate*, **2**, 321-340.

Krishnamurti, T.N., Bedi, H.S. and Subramaniam, M., 1990, "The summer monsoon of 1998", *J. Meteorol. and Atmos. Phys.*, **42**, 19- 37.

Parthasarathy, B. and Pant, G.B., 1985, "Seasonal relationship between Indian summer monsoon rainfall and the southern oscillation", *J. Climatol.*, **5**, 143-150.

Rajeevan, M., 1991, "Upper air circulation and thermal anomalies over India and neighbourhood *vis-a-vis* Indian summer monsoon activity", *Mausam*, **42**, 155-160.

Rajeevan, M., 1993a, "Upper tropospheric circulation and thermal anomalies over central Asia associated with major droughts and floods in Indian" *Curr .Sci.* **64**, 244-247.

Rajeevan, M., 1993b, "Inter-relationship between NW Pacific typhoon activity and Indian summer monsoon on inter-annual and intra-seasonal timescales", *Mausam*, **44**, 109-111.

Shankar Rao, M., Lau, K.M., and Yang, S., 1996, "On the relationship between Eurasian snow cover and Asian summer monsoon", *Int. J. Climatol*, **16**, 605-616.

Shukla, J., 1987, In Fein, J. and Stephens, P. (eds), Monsoons, Wiley Interscience, New York, 399-463.

Shukla, J. and Paolino, D.A., 1983, "The southern oscillation and long range forecasting of summer monsoon rainfall over India", *Mon. Wea . Rev.*, **111**, 1830-1837.

Singh, O.P. and Pai, D.S., 1996, "An oceanic model for the prediction of southwest monsoon rainfall over India", *Mausam*, **47**, 91-98.

Thapliyal, V. and Kulshrestha, S.M., 1992, "Recent models for long range forecasting of southwest monsoon rainfall in India", *Mausam*, **43**, 239-248.

Verma, R.K., 1982, "Long range prediction of monsoon activity" A synoptic diagnostic study", *Mausam*, **33**, 35-44.

Vernerkar, A.D., Zhou, J. and Shukla, J., 1995, "The effect of Eurasian snow cover on the Indian monsoon", *J. Climate.*, **8**, 248- 266.

Yang, S., 1996, "ENSO - snow - monsoon association and seasonal-interannual predictions", *Int. J. Climatol.*, **16**, 125-134.

Yasunari, T., 1987, "Global structure of the El-Nino/Southern oscillation. Part II. Time evolution", *J. Met. Soc., Japan*, **65**, 81-102.

Yasunari, T., Kitoh, A. and Tokioka, T., 1991, "Local and remote responses to excessive snow mass over Eurasia appearing in the northern spring and summer climate-a study with the MRI. GCM", *J. Met. Soc., Japan*, **69**., 473-487.

Yasunari, T. And Seki, Y., 1992, "Role of the Asian monsoon on the interannual variability of the global climate system", *J. Met. Soc., Japan.*, **70**, 177-189.